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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

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MANUAL

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THE CLOSED VESSEL TEST AND DETERMINATION OF BALLISTIC PROPERTIES OF GUN PROPELLANTS

M.R. GRIVELL

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THE CLOSED VESSEL TEST AND DETERMINATION OF BALLISTIC PROPERTIES OF GUN PROPELLANTS

M. R. Grivell

S U M M A R Y

This manual details the methods by which closed vessel test data are used to calculate values of ballistic properties of gun propellants. The properties of interest are force, vivacity, quickness, predicted gun pressure and predicted charge weight. Details are also included on a homogeneity test which can be applied to the test data.

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1. INTRODUCTION

All propellants manufactured for the Australian Defence Forces by the Department of Defence Support are required to meet specifications regarding chemical composition, shape and ballistic properties. The responsibility for independently testing samples of these propellants after manufacture to ensure that they meet these specifications has been given to WSRL. Nitrocellulose Propellants Group (NCP) monitors chemical composition, shape and stabilizer content of the propellants and Gun Propulsion Research Group (GPR) monitors their ballistic properties.

This manual describes how the ballistic properties of a propellant are determined by burning a sample of the propellant in the closed vessel. The methodology used to determine the homogeneity of a propellant lot is detailed in Appendix I and a sample calculation, showing how the effect of the propellant inhomogeneity on the muzzle velocity of the gun is determined, is given in Appendix II. Appendix III contains a table of variance ratios used in the homogeneity calculations and this has been drawn from reference 1.

2. THE CLOSED VESSEL TEST

The closed vessel test consists of burning a weighed quantity of gun propellant in a vessel of constant volume.

The liner of the vessel is a thick walled nickel-chrome-molybdenum steel tube. It is inserted into the vessel body which is a heat-treated nickel steel tube that has been threaded at each end to receive two closing blocks.

One of the closing blocks carries a piezoelectric pressure transducer which produces an electrical signal that is a function of the pressure developed in the vessel. The sensing element in the transducer is a cylinder of tourmaline 12.7 mm in diameter and 6.3 mm thick which has been cut in such a manner, with reference to its electrical axis, that hydrostatic pressure applied to the crystal results in a positive electrostatic charge appearing on one face and an equal and opposite electrostatic charge appearing on the other face. The other closing block is fitted with electrodes for igniting the propellant charge and also contains a valve to exhaust the gases produced in the test. The same method of obturation is used at both ends of the vessel and consists of soft annealed brass rings that fit half into seatings on the liner and half into seatings in the appropriate block.

The ignition element consists of a short length of thin nichrome wire threaded through an igniter bag containing 1.30 g (20 grains) of gun powder and connected between the two electrodes. A dc voltage (12 V) is then applied to the electrodes from the data recording instrument resulting in ignition of the propellant.

The electrical signal produced by the pressure transducer is fed via a coaxial cable to the data recording instrument and a record of the rate of change of pressure with time (dP/dt) against the pressure developed in the vessel (P) is produced on an X-Y plotter.

The record is analysed by measuring dP/dt at a particular pressure, P_a, known as the 'action pressure' and the maximum pressure, P_m, developed in the vessel. These values are used as input data to a computer program to determine values for relative quickness (RQ), relative force (RF) and relative vivacity (RA). A full description of the program and the theory of closed vessel testing are described in reference 1.

3. BALLISTIC CALCULATIONS

The information required from the analysis of a propellant lot is:

(a) the ballistic level,

(b) the homogeneity of the propellant lot, and

(c) the ballistic assessment.

3.1 Ballistic level

The ballistic level of a propellant lot undergoing test in the closed vessel is the mean values of its force and vivacity relative to the mean values of force and vivacity for the standard propellant lot.

The force (λ) of a propellant is closely related to the maximum pressure (P_m) developed by combustion of the propellant in the closed vessel and can be expressed by the relationship

$$\lambda = k.P_m \tag{1}$$

where k is a constant and is a function of loading density, covolume and heat losses.

The force is directly related to the energy of the propellant and hence provides an indication that the propellant composition is correct. P_m is obtained from the dP/dt versus P record (see figure 1) and is the point marked G.

Vivacity (A) is defined as the rate of change of pressure with time (dP/dt) divided by the maximum pressure (P_m)

$$A = (dP/dt)/P_m \tag{2}$$

Hence vivacity is a measure of the rate of energy production of a propellant. The particular value of dP/dt is read from the dP/dt versus P record at the action pressure, P_a, and is shown at point H in figure III.1.

P_a is chosen to give optimum agreement between the gun and the closed vessel for a particular propellant type and a general guide for determining the value of P_a is given by the expression

$$P_a = 0.625\ P_m \tag{3}$$

A more accurate method for determining P_a is described in reference 2.

Insofar as ballistic characteristics are concerned, differences between two propellants in respect of performance in the gun will arise chiefly from differences in force and/or vivacity between the two propellants. The combined effect of these parameters, Quickness (Q), is defined as

$$Q = \text{force} \times \text{vivacity} \tag{4}$$

$$= \lambda . A \tag{5}$$

Substituting equations (1) and (2) into equation (4) gives

$$Q = k.dP/dt \tag{6}$$

It is usual to compare the ballistic level of a propellant against the ballistic level of a standard propellant of the same type and composition. Consequently, the following definitions apply

$$\text{Relative force (RF)} = \frac{\text{force of test propellant}}{\text{force of standard propellant}} \tag{7}$$

$$= \frac{(P_m)_t}{(P_m)_s} \tag{8}$$

$$\text{Relative vivacity (RA)} = \frac{\text{vivacity of propellant}}{\text{vivacity of standard}} \tag{9}$$

$$= \frac{(dP_a/dt/P_m)_t}{(dP_a/dt/P_m)_s} \tag{10}$$

$$\text{Relative quickness (RQ)} = \frac{\text{quickness of test propellant}}{\text{quickness of standard propellant}} \tag{11}$$

$$= \frac{(dP_a/dt)_t}{(dP_a/dt)_s} \tag{12}$$

Where the subscripts t and s refer to the test sample and the standard sample respectively.

RF, RA and RQ are usually given as percentages and consequently equations (8), (10) and (12) must be multiplied by 100.

3.2 Homogeneity

The homogeneity test is a statistical computation that is carried out on the data obtained from the closed vessel test in order to ascertain how homogeneous the propellant is between the various boxes and within the individual boxes that comprise the propellant lot.

The statistical methodology used in the test is fully described in Appendix I and a sample computation on results achieved in a closed vessel test given in Appendix II.

3.3 Ballistic assessment

The ballistic assessment of a quantity of propellant involves the estimation of the propellant predicted charge weight (PPCW) and the muzzle velocity or gun pressure (depending on the type of gun in which the propellant is to be fired) to be expected from the propellant under test. These parameters are calculated from the mean relative values of force and vivacity obtained from the ballistic level calculations and from a variety of constants called increment factors that are derived from equations of internal ballistics.

There are two classes of guns:

(a) velocity adjusted guns

(b) pressure adjusted guns.

A velocity adjusted gun is one in which the charge weight of gun propellant loaded into the canister is adjusted to give the projectile the 'approved muzzle velocity' (AMV).

A pressure adjusted gun is one in which the charge weight of gun propellant loaded into the canister is adjusted to give the 'approved gun pressure' (AGP).

The following theoretical incremental formulae apply:

$$\frac{dV}{V} = x\frac{dA}{A} + y\frac{dF}{F} + z\frac{dC}{C} \tag{13}$$

$$\frac{dP}{P} = u\frac{dA}{A} + v\frac{dF}{F} + w\frac{dC}{C} \tag{14}$$

Where V = muzzle velocity
P = pressure in the gun
A = vivacity of propellant
F = force of propellant
C = propellant charge weight

Equations (13) and (14) are quite general; the increment factors (x, y, z, u, v and w) are determined for any particular set of predicted conditions.

$$\frac{dV}{V} = \frac{V_{std} - V_{exp}}{V_{std}} \tag{15}$$

$$\frac{dP}{P} = \frac{P_{std} - P_{exp}}{P_{std}} \tag{16}$$

$$\frac{dA}{A} = \text{Relative Vivacity} - 100 \tag{17}$$

$$\frac{dF}{F} = \text{Relative Force} - 100 \tag{18}$$

dC = incremental adjustment in charge weight

x,y and z are the velocity increment factors and u, v and w are the pressure increment factors. These factors relate to the propellant/weapon system and are derived from internal ballistic theory.

For particular service and proof conditions, the following definitions apply

Approved Muzzle Velocity	=	V_o
Velocity of Adjustment	=	V'
Approved Gun Pressure	=	P_o
Pressure of Adjustment	=	P'

The 'approved muzzle velocity' (V_o) and the 'approved gun pressure' (P_o) are the velocity and pressure obtained by firing a prescribed weight of standard propellant in a new gun. Under standard proof conditions, however, the muzzle velocity and gun pressure will differ from the approved values for the prescribed weight of propellant since factors such as temperature, projectile weight and perturbations due to instrumentation affect the results. These particular values of muzzle velocity and gun pressure are known as 'velocity of adjustment' (V') and 'pressure of adjustment' (P') respectively.

If a charge weight is sought which will achieve V' at proof, then the increment factors of equations (13) and (14) and the standard conditions for equations (15) and (16) must refer to these conditions and dV in equation (15) must equal zero. Hence equation (13) can be rearranged to

$$dC = -\frac{Cx}{z} \cdot \frac{dA}{A} - \frac{Cy}{z} \cdot \frac{dF}{F} \tag{19}$$

The 'predicted propellant charge weight', alternatively referred to as the 'propellant proof charge weight', (PPCW) can then be readily determined using the relationship

$$PPCW = CW_{std} + dC \tag{20}$$

where CW_{std} is the Approved Charge Weight.

PPCW is the predicted weight of the particular lot of propellant required to give V' in the new gun when fired under standard proof conditions.

CW_{std} is the amount of standard propellant required to give

V_o and P_o when fired in a new gun.

The pressure expected to be achieved in the gun using the PPCW of the propellant under test can be determined. Substituting equation (19) into equation (14) gives the expression

$$dP = (u - \frac{wx}{z})\ P\ .\ \frac{dA}{A} + (v - \frac{wy}{z})\ P\ .\ \frac{dF}{F} \tag{21}$$

The predicted gun pressure (PGP) is then given by

$$PGP = GP_{std} + dP \tag{22}$$

where GP_{std} is the pressure achieved in a new gun when fired under standard proof conditions using the CW_{std} of standard propellant.

There are certain guns in which the prime ballistic requirement is the establishment of consistent pressure conditions (rather than velocity). These are called pressure adjusted guns. Accordingly, the charge weight in these guns is adjusted to give P' under standard proof conditions and hence the term dP in equation (14) must equal zero. Equation (14) can then be rearranged to

$$dC = -\frac{Cu}{w}\ .\ \frac{dA}{A} - \frac{Vu}{w}\ .\ \frac{dF}{F} \tag{23}$$

The PPCW is then determined from equation (20). The muzzle velocity expected to be achieved in the gun using the PPCW of the propellant under test can be determined using equation (13). Substituting equation (23) into equation (13) gives the following expression

$$dV = \left(x - \frac{uz}{w}\right) V \cdot \frac{dA}{A} + \left(y - \frac{zv}{w}\right) V \cdot \frac{dF}{F} \tag{24}$$

the predicted muzzle velocity (PMV) is then given by

$$PMV = MV_{std} + dV \tag{25}$$

where MV_{std} is the muzzle velocity achieved when CW_{std} of standard propellant is fired in a new gun under standard proof conditions.

REFERENCES

No.	Author	Title
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2	Grivell, M.R.	"Automatic Data Processing of Closed Vessel Results". WSRL-0068-TM, January 1979
3	Ministry of Defence (UK)	"A Manual on Proof of Propellants for Guns and Mortars (P.26)". October 1971
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APPENDIX I

THE HOMOGENEITY TEST

The homogeneity test is a statistical test carried out on the absolute values of maximum pressure and vivacity obtained from burning samples of a propellant lot in the closed vessel.

The normal procedure is to fire two samples of the propellant from each of eight boxes and repeat the determination on a second occasion using a further selection of eight boxes.

The methodology used in the test is as follows:

(1) Tabulate the data in the form as shown in Table I.1:

TABLE I.1

OBSERVATION	BOX NO.				
	1	2	3	.....	k
1	x_{11}	x_{21}	x_{31}	.....	x_{k1}
2	x_{12}	x_{22}	x_{32}	.....	x_{k2}
. . . . .	. . . . .	. . . . .	. . . . .		. . . . .
n	x_{1n}	x_{2n}	x_{3n}	.....	x_{kn}
SUM	s_1	s_2	s_3	.....	s_k

where x_{11}, x_{12}, x_{13}, ...x_{kn} are the individual observations of P_m (or vivacity) and s_1, s_2, s_3 .... s_k are the sums of the observations in each column.

(2) Calculate the grand sum of observations, S, and the total number of observations, N

$$S = s_1 + s_2 + \ldots\ldots s_k \qquad (I.1)$$

$$N = n_1 + n_2 + \ldots\ldots n_k \qquad (I.2)$$

(3) Calculate the crude total sum of squares

$$\Sigma x^2 = x_{11}^2 + x_{12}^2 + x_{13}^2 + \ldots\ldots x_{kn}^2 \qquad (I.3)$$

(4) Calculate the crude sum of squares between samples

$$\Sigma\left(\frac{S_i^2}{n_i}\right) = \frac{S_1^2}{n_1} + \frac{S_2^2}{n_2} + \frac{S_3^2}{n_3} + \ldots\ldots \frac{S_k^2}{n_k} \qquad (I.4)$$

(5) Calculate the correction factor ξ due to the mean

$$\xi = \frac{S^2}{N} \qquad (I.5)$$

(6) Calculate the total sum of squares

$$= (I.3) - (I.5) \qquad (I.6)$$

$$= \Sigma x^2 - \xi$$

(7) Calculate the sum of squares between groups

$$= (I.4) - (I.5) \qquad (I.7)$$

$$= \Sigma\left(\frac{S_i^2}{n_i}\right) - \xi$$

(8) Calculate the degrees of freedom (d.o.f.)

(a) <u>Between Groups</u>

$$\text{d.o.f.} = \text{number of groups} - 1 \qquad (I.8)$$

$$= k - 1$$

(b) <u>Within Groups</u>

$$\text{d.o.f.} = N - k \qquad (I.9)$$

(c) Total degrees of freedom

$$\text{d.o.f.} = \text{total number of observations} - 1 \qquad (I.10)$$

$$= N - 1$$

(9) Construct the analysis of variance table as shown in Table I.2.

TABLE I.2

Source of Variation	Sum of Squares	Degrees of Freedom	Variance
Between groups	$\Sigma\left(\frac{S_i^2}{n_i}\right) - \xi$	$k - 1$	V_1
Within groups	$\Sigma x^2 - \Sigma\left(\frac{S_i^2}{n_i}\right)$	$N - k$	V_2
Total	$\Sigma x^2 - \xi$	$N - 1$	

The variance given in the table is computed from the formula:

$$\text{Variance} = \frac{\text{sum of squares}}{\text{d.o.f.}} \qquad (I.11)$$

(10) Calculate the variance ratio, F.

$$F = \frac{\text{larger variance}}{\text{smaller variance}} \qquad (I.12)$$

(11) Enter the table of variance ratios, F, (see Appendix III) with ϕ_1 = d.o.f. (larger variance) and ϕ_2 = d.o.f. (smaller variance) and note the F value given at the intersection of the ϕ_1 column and ϕ_2 row at the 5% level of probability.

If the calculated value of F (equation (I.12)) is greater than that determined from the table, then the result is more significant than the 5% level of significance. If however, the calculated value of F is less than the F value obtained from the table in Appendix III, then the result is not as significant as the level of the table.

(12) Calculate the standard deviation, σ, of a single round using the formula

$$\sigma = \sqrt{\frac{\Sigma x^2 - \xi}{N - 1}} \tag{I.13}$$

(13) Calculate σ as a percentage of the mean

$$Y = \frac{100.\sigma}{\bar{x}} \tag{I.14}$$

(14) Calculate the effect of the standard deviation on the muzzle velocity using the following formulae

(a) For Force

$$A = \frac{Y.y.(V \text{ of } A)}{100} \tag{I.15}$$

where y = increment factor for force.

(b) For Vivacity

$$B = \frac{Y.x.(V \text{ of } A)}{100} \tag{I.16}$$

where x = increment factor for vivacity.

(15) Calculate the estimated effect of the propellant variability in gun standard deviation, σ_p^2, using the formula

$$\sigma_p^2 = \frac{A^2 + B^2}{C^2} \tag{I.17}$$

where C^2 for multiperforated propellant (on a weight for weight basis) is given by the expression

$$C^2 = \frac{X}{Y} \tag{I.18}$$

where X = nominal charge weight in gun
Y = charge weight in closed vessel,

and for stick propellant (on the number of sticks basis) is given by the expression

$$C^2 = \frac{X}{Y}\cdot\frac{P}{Q} \tag{I.19}$$

where P = length of charge in closed vessel
Q = length of charge in gun.

(16) Calculate the total estimated effect of propellant and gun on muzzle velocity (σ_t) using the expression

$$\sigma_t = \sqrt{\sigma_p^2 + \sigma_r^2} \qquad (I.20)$$

where σ_r is a constant for each type of gun.

(17) Calculate the expected mean deviation in the muzzle velocity (EMD) at gun proof using the expression

$$EMD = K.\sigma_t \qquad (I.21)$$

where K is a statistical constant relating to the number of rounds fired.

(18) Calculate the 95% lower limit on mean deviation of muzzle velocity (MD_{95}) using the formula

$$MD_{95} = K'\sigma_t \qquad (I.22)$$

where K' is a statistical constant.

APPENDIX II

SAMPLE CALCULATION OF HOMOGENEITY TEST

The following calculation is based on the detail provided in Appendix I and has been carried out using Imperial units. This is the required practice in the Australian Defence Forces and Department of Defence Support propellant manufacturing factories for closed vessel work.

Details of the propellant undergoing test are as follows:

Propellant Type:	MNF2P/S 168-048
Propellant Lot No:	Lot MDK 782
Date of Test:	21 August 1981
Standard Propellant:	MNF 2P/S 168-048 Lot RNB31
Gun:	QF 4.5 inch MK V
V of A:	2437 ft/s
Approved Muzzle Velocity:	2430 ft/s
dV/V	7/2430 = + 0.29%
Approved Charge Weight	13 lb 2 oz 0 drm
Approved Gun Pressure	22.2 tsi

TABLE II.1 INCREMENT FACTORS FOR PROPELLANT MNF2P/S 168-048

u	1.74
v	1.87
w	2.47
x	0.23
y	0.61
z	0.69
σ_r^2	6.15 $ft^2.s^{-2}$
C^2	9.09
K	0.7137
K'	0.315

(a) Analysis for P_m

ROUND	BOX NO. 26	121	191	263	326	369	440	501
1	14.212	14.304	14.291	14.289	14.276	14.298	14.228	14.200
2	14.280	14.211	14.291	14.417	14.429	14.356	14.331	14.432
SUM	28.492	28.515	28.582	28.706	28.705	28.654	28.559	28.632

(1) Using equation (I.3): $\Sigma P_m^2 = 3273.21098$

(2) Using equation (I.4): $\Sigma \frac{sum}{2}^2 = 3273.15055$

(3) Using equation (I.5): $\xi = 3273.12713$

(4) Construct the analysis of variance table.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance
Between boxes Within boxes	0.02342 0.06043	7 8	0.003346 0.007554
Total	0.08385	15	0.010900

(5) Mean $P_m = \frac{\Sigma P_m}{16}$

$= 14.303$ tsi

(6) Using equation (I.12)

$$F = \frac{0.007554}{0.003346}$$

$$= 2.26$$

(7) From table in Appendix III for $\phi_1 = 8$, $\phi_2 = 7$

$$F = 3.68$$

Hence the result in P_m is not significant at the 5% level.

(8) Using equation (I.13)

$$\sigma = \sqrt{\frac{0.08385}{15}}$$

$$= 0.0748 \text{ tsi}$$

(9) Using equation (I.14)

$$Y = \frac{100 \times 0.0748}{14.303}$$

$$= 0.523\%$$

(10) Using equation (I.15) and the detail supplied in the table of

increment factors given in Table II.I, the effect of variance in force on muzzle velocity can be determined.

$$A = \frac{0.523 \times 0.61 \times 2437}{100}$$

$$\doteq 7.77 \text{ ft/s}$$

(b) Analysis for Vivacity

ROUND	BOX NO							
	26	121	191	263	326	369	440	501
1 2	91.90 94.39	92.39 93.40	91.24 92.79	93.06 91.86	93.66 93.11	94.23 94.18	92.00 93.95	92.12 94.70
Sum	186.29	185.79	184.03	184.92	186.77	188.41	185.95	186.82

(1) Using equation (I.3): $\Sigma \text{ vivacity}^2 = 138583.319$

(2) Using equation (I.4): $\dfrac{\Sigma \text{ sum}^2}{2} = 138572.4057$

(3) Using equation (I.5): $\xi = 138566.34$

(4) Construct the analysis of variance table.

Source of Variance	Sum of Squares	Degrees of Freedom	Variance
Between boxes Within boxes	6.0657 10.9133	7 8	0.86653 1.36416
Total	16.979	15	1.13193

(5) Mean vivacity $= \dfrac{\Sigma \text{ vivacity}}{16}$

$$= 93.06 \text{ s}^{-1}$$

(6) Using equation (I.12)

$$F = \frac{1.36416}{0.86653}$$

$$= 1.574$$

(7) From the table given in Appendix III, for $\phi_1 = 8$, $\phi_2 = 7$

$$F = 3.73$$

ie the result is not significant at the 5% level.

(8) Using equation (I.13)

$$\sigma = \sqrt{\frac{16.979}{15}}$$

$$= 1.064 \ s^{-1}$$

(9) Using equation (I.14)

$$Y = \frac{100 \times 1.064}{93.06}$$

$$= 1.143\%$$

(10) Using equation (I.16) and the detail given in the table of increment factors, the effect of variance in vivacity on the muzzle velocity can be determined

$$B = \frac{1.143 \times 0.23 \times 2437}{100}$$

$$= 6.409 \ ft/s$$

(c) Analysis of effect of propellant variability on muzzle velocity

(1) The estimated effect of propellant variability (σ_p^2) on gun standard deviation can be determined using equation (I.17)

$$\sigma_p^2 = \frac{7.77^2 + 6.409^2}{9.09}$$

$$= 11.16 \ ft^2/s^2$$

(2) The estimated total variability in muzzle velocity (σ_t) is determined from equation (I.20)

$$\sigma_t = \sqrt{11.16 + 6.15}$$

$$= 4.16 \ ft/s$$

(3) Expected mean deviation (EMD) can be determined using equation (I.21)

$$EMD = K.\sigma_t$$

$$= 0.7137 \times 4.16$$

$$= 2.969 \text{ ft/s}$$

The 95% lower limit on the mean deviation of muzzle velocity MD_{95} can be determined from equation (I.22)

$$MD_{95} = K'.\sigma_t$$

$$= 0.315 \times 4.16$$

$$= 1.310 \text{ ft/s}$$

APPENDIX III

TABLE OF VARIANCE RATIOS

The variance ratio test (or F test) is used in Appendix I to statistically determine the level of inhomogeneity in a propellant lot undergoing test.

The variance ratio F is defined as

$$F = V_1/V_2 \tag{I.23}$$

where V_1, V_2 are variances and $V_1 > V_2$. Associated with the value of F are the degrees of freedom ϕ_1, ϕ_2 on which both V_1 and V_2 are based.

Values of F have been computed at various levels of probability for the degrees of freedom ϕ_1 and ϕ_2 and values of F for up to 10 degrees of freedom at the 5% level of probability are presented in Table III.1

TABLE III.1

		ϕ_1 (corresponding to greater mean square)									
		1	2	3	4	5	6	7	8	9	10
ϕ_2	1	161.0	199.0	216.0	225.0	230.0	234.0	237.0	239.0	241.0	242.0
	2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4
	3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
	4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
	5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
	6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
	7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
	8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
	9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
	10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98

Variance ratios for degrees of freedom ϕ_1, ϕ_2 from 1 to 10 for the 5% level of probability.

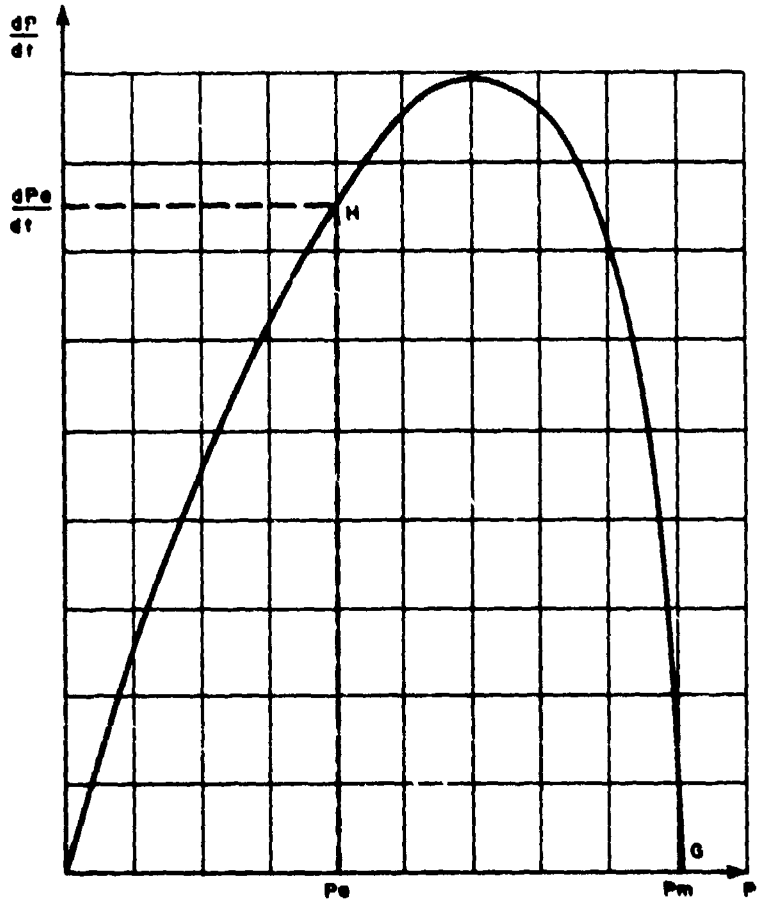

Figure III.1 A typical record of dP/dt versus P showing the measuring points

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This report details the methods by which closed vessel test data are used to calculate values of ballistic properties of gun propellants. The properties of interest are force, vivacity, quickness, predicted gun pressure and predicted charge weight. Details are also included on a homogeneity test which can be applied to the test data.

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